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(71) Applicant: LOCKHEED MARTIN CORPORATION
[US/US]; 6801 Rockledge Drive, Bethesda, MD 20817
(US).

(72) Inventors: HERSHEY, John, Erik; 4 Vines Road, Ball-ston Lake, NY 12019 (US). HOCTOR, Ralph, Thomas; 4 Horizon Drive, Saratoga Springs, NY 12866 (US). KO-RKOSZ, Richard, August; 26 Riverview Drive, Rotter-dam Junction, NY 12150 (US). PUCKETTE, Charles, Mcdonald, IV; 28 Via Maria Drive, Scotia, NY 12302 (US).

(74) Agent: GROLZ, Edward, W.; Scully, Scott, Murphy & Presser, 400 Garden City Plaza, Garden City, NY 11530 (US).

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(54) Title: DIGITAL RECEIVING SYSTEM FOR DENSE ENVIRONMENT OF AIRCRAFT

(57) Abstract: The capacity of a Mode-S ADS-B surveillance radar system is increased by sectorizing the radar system by the use of a directional array of Mode-S, quarter wavelength, single element, stub antennas. The ensemble of signals from the array of Mode-S antenna elements is processed electronically. The signal processing/receiver architecture increases the capacity of the Mode-S ADS-B system to be capable of effectively functioning within a highly congested airspace.

DIGITAL RECEIVING SYSTEM FOR DENSE ENVIRONMENT OF AIRCRAFT

BACKGROUND OF THE INVENTION

The present invention concerns a digital receiving system for an ADS-Mode-S system which is capable of effectively functioning and operating competently within a highly congested airspace having a dense environment of aircraft.

In an ADS (Automatic Dependent Surveillance) system, an aircraft periodically broadcasts its state vector (horizontal and vertical position, horizontal and vertical velocity). The aircraft relies upon on-board navigation sources such as an on-board GPS (Global Positioning System) receiver and its broadcast transmission systems to provide surveillance information to other users.

The ADS-Mode-S concept is based upon the use of a Mode S squitter which provides a periodic broadcast (i.e., "squitter") of the aircraft's position, altitude, identification, and other information.

At the present time, a Mode-S 56-bit squitter is used by the Traffic Alert and Collision Avoidance System (TCAS) to detect the presence of Mode-S equipped aircraft. The TCAS listens for Mode-S squitters and extracts a 24-bit Mode-S address, and uses this address for discrete interrogation. The longer 112 bit squitter replies contain, in addition to other data, 56-bits referred to as an ADS message field. The bits in the ADS message field convey data including (1) barometric altitude, (2) latitude, and (3) longitude. Aircraft equipped with a Mode-S transponder and a GPS receiver

determine their position once every second, and this positional information is inserted into the 56-bit ADS message field of the long squitter reply, and broadcast twice every second to increase the probability of a

5   successful reception. The current 56-bit short squitter continues to be broadcast once every second for compatibility with the TACS. Thus, potential interference is caused by both short and long squitter transmissions.

10   The present invention enhances the capability of a basic ADS-Mode-S system to receive ADS-Mode-S messages error free by using an array of basic Mode-S antenna elements, and processes the ensemble of signals electronically. The subject invention provides a signal

15   processing/receiver architecture which enhances the capability of a basic ADS-Mode-S system to receive ADS-Mode-S messages error free, so that it is capable of effectively functioning within a highly congested airspace.

20   The information provided by an ADS-Mode-S message can assist pilots of nearby aircraft in the implementation of free flight plans, and is also monitored by ATS (Air Traffic Services) to ensure that an aircraft maintains conformance to its intended

25   trajectory.

             Free Flight is a concept which is being developed, tested, and implemented incrementally by the Federal Aviation Administration (FAA) and the aviation community. Free Flight is designed to enhance the safety

30   and efficiency of the National Airspace System (NAS). The concept moves the NAS from a centralized command-and-control system between pilots and air traffic controllers

to a distributed system that allows pilots, whenever
practical, to choose their own route and file a flight
plan that follows the most efficient and economical
route.

5   The realization of free flight will require
cooperative decision making among aircraft. One of the
key system considerations for implementing such
realization is an adequate surveillance architecture.
Today navigation and surveillance is accomplished

10   primarily by ground equipments, i.e., beacon radars and
primary radars that do not operate in concert.

Radars are used today in two ways in air
traffic control. The first, primary radar usage is an
equipment which measures distance to an aircraft by

15   measuring the round-trip time of a pulse from the radar
to the plane which scatters the pulse. Some of the
scattered or reradiated energy is detected by the radar
receiver which is usually collocated with the radar
transmitter. The second type of radar which is used in

20   air traffic control is termed secondary radar. This genre
of radar requires a transponder to be installed aboard an
aircraft. When the aircraft is illuminated by an
interrogation pulse of a secondary radar, the transponder
broadcasts a digital signal which may convey aircraft

25   identification and altitude.

ADS-B (Automatic Dependent Surveillance-B) is a
function on an aircraft or a surface vehicle operating
within the surface movement area which periodically
broadcasts its state vector (horizontal and vertical

30   position, horizontal and vertical velocity) and other
information. ADS-B is automatic because no external
stimulus is required to elicit a transmission; it is

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dependent because it relies on on-board navigation
sources and on-board broadcast transmission systems to
provide surveillance information to other users. The
aircraft or vehicle originating the broadcast may or may

5   not have knowledge of which users are receiving its
broadcast; any user, either aircraft or ground-based,
within range of the broadcast, may choose to receive and
process ADS-B surveillance information. With ADS-B, ATS
(Air Traffic Services) would monitor the ADS-B messages

10   ensuring that an aircraft maintains conformance to its
intended trajectory. The increased accuracy and
additional information directly provided by the aircraft
(via ADS-B), in comparison to radar-based monitoring,
will result in quicker blunder detection and reduce false

15   alarms.
           The National Airspace System (NAS) Architecture
(Dec. 1997), section 7.9, notes that ADS-B is initially
intended as a surveillance system, not an avoidance
system. Broader application will depend upon the

20   creation of an ADS-B ground surveillance capability. As
restrictions are relaxed and flexibility enhanced, it is
expected that ADS-B will be a key component leading to
both free flight and IFR (Instrument Flight Rules)
cooperative-separation.

25   The ADS-B system is required to operate
competently within a peak traffic environment. This
requirement is based upon the Los Angeles Basin traffic
model. The ADS-B network must be designed to accommodate
expected future peak airborne traffic levels, as well as

30   any airport surface units within range. The expected peak
instantaneous airborne count (IAC) in the US has been
given by the Los Angeles Basin traffic model. Traffic

distributions for the Los Angeles Basin, as well as for a
number of other measured terminal area distributions, are
closely approximated by a uniform density function
(cumulative number increasing as the square of the range
5   from the center) out to about 15 nmi. From this point to
60 nmi, the cumulative number of aircraft is proportional
to the range. The approximate IAC distribution for the
Los Angeles Basin model has a peak count of 750 aircraft.
This does not include aircraft or vehicles which are
10   operating on the airport surface. Estimates for these
additional traffic elements are 100 vehicles in motion
and 150 surface units at rest. Thus, the total traffic
density may total to 1,000 units within a radius of 60
nmi. This does not include any adjacent sector en route
15   traffic.

In Mode S was originally developed as a requisite
surveillance improvement for Mode A/C secondary
surveillance radar (Air Traffic Control Radar Beacon
System or ATCRBS). In these modes, an interrogation at
20   1030 MHz triggers a response at 1090 MHz from an aircraft
equipped with a Mode S transponder. Mode A consists of an
8 microsecond interrogatory which is answered with a 20.3
microsecond replay conveying the aircraft identification
code. In Mode C, the interrogatory is 21 microseconds and
25   the reply is 20.3 microseconds and yields the aircraft
altitude. Typically an aircraft is illuminated with Mode
A and then Mode C.

In Mode S, using the same frequency plan, an
interrogatory consists of a preamble of duration 3.5
30   microseconds followed by a data block of either 16.26
microseconds or 30.26 microseconds conveying 56 or 112
data bits. (One and a quarter microseconds are used for a

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synchronization phase reversal training.) The
interrogatory is DPSK at a rate of 4 megabits per second.
The Mode S reply comprises a 6 microsecond preamble
followed by a data block of 56 or 112 microseconds. The
5   signaling is PPM at a data rate of 1 megabit per second.

The ADS-Mode S has been described as a system
concept that merges the capabilities of Automatic
Dependent Surveillance (ADS) and the Mode S beacon radar.
The result is an integrated system for seamless
10   surveillance and data link which permits equipped
aircraft to participate in ADS or beacon ground
environments. This offers many possibilities for
transitioning from a beacon to an ADS based surveillance
system.

15   The ADS-Mode S concept is based upon the use of
a Mode S squitter. The current Mode S squitter is a
spontaneous, periodic (once per second) 56 bit broadcast
message containing the Mode S 24 bit address. This
broadcast is provided by all Mode S transponders and is
20   used by the Traffic Alert and Collision Avoidance System
(TCAS) to acquire nearby Mode S equipped aircraft. The
aircraft position messages would be transmitted at an
average rate of 2 Hz. The actual spacing between
squitters would be randomized slightly to prevent
25   synchronous interference between two aircraft. The
spacing between the position squitters would be uniformly
distributed between 0.4 and 0.6 seconds.

ADS-B transponders will provide a periodic
broadcast (i.e., "squitter") of the aircraft's position,
30   altitude, identification, and other information. By the
year 2005, these transponders will also respond to
interrogations from SSRs (Secondary Surveillance Radars).

The most accurate (and intended) position reference will be the GPS receiver carried on board the aircraft. The ADS-B transponder will be a direct replacement for Mode A/C transponders or an upgrade to Mode S transponders.

5   The operating capacity of the proposed ADS-Mode S system is believed to be limited by interference on the 1090 frequency which consists of transponder replies to ATCRBS interrogations (20 microseconds in duration), "short" (56--bit) Mode S replies, and "long" Mode S
10   replies (112--bit).

The capacity is modeled by assuming a Poisson arrival at a receiver. The ADS-Mode S squitter is assumed to be received without error if no other Mode S replies overlap it and there is at most one ATCRBS reply that
15   overlaps it. From these assumptions, it has been computed that the probability, p, that an ADS-Mode S squitter is received without error is,

$$p = (1 + t_1 n_1 m) e^{-t1n1m} * e^{-t2n2m} * e^{-t3n3m} \qquad (1)$$

20   where

n1 is the average number of ATCRBS replies per aircraft per second,

n2 is the average number of short Mode S
25   replies per aircraft per second,

n3 is the average number of long Mode S replies per aircraft per second,

m is the number of aircraft that may initiate interfering replies,
30   t1 is the time duration that the ADS-Mode S squitter is vulnerable to the start of an ATCRBS reply,

t2 is the time duration that the ADS-Mode S squitter is vulnerable to short Mode S replies,

t3 is the time duration that the ADS-Mode S squitter is vulnerable to long Mode S replies.

{ti} is estimated as:

t1=0.000140 seconds,

t2=0.000184 seconds, and

t3=0.000240 seconds.

From these values an estimate is calculated of the system's capacity. An update rate of about 5 seconds is required with reliability 99.5% or better.

This is a bit conservative in light of the following. Acceptable combinations of report update period (T) and update probability (P) are given by the formula $(1 - P)^{TC/T} \leq 0.01$

where TC is the 99th percentile report update period. For example, for conflict avoidance, TC=6 sec.; a report update period of T=3 would require P=0.9 or greater. As a second example, for conflict avoidance, if P=0.5, then T must be 0.9 seconds or less. TC represents a coast period, that is, the maximum allowable time between state vector report updates.

Three cases are posited distinguished by the average number of ATCRBS replies per aircraft per second n1. The most stringent of the cases is for n1=120. The other parameters are fixed for all three cases with n2=8 and n3=6. They determine that the aircraft capacity is 86 planes under these assumptions. They note, however, that this result is for an omnidirectional antenna. A 6

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sector antenna (en-route) can improve this number by a
factor of two and a half to 215 aircraft.

The capacity is markedly increased as n1 is
decreased to zero, however, it is insufficient to handle
the full pressure of the Los Angeles Basin traffic model.
There are things that can be done to try to increase the
capacity. One thing that is tempting is to increase the
transmission rate, i.e., increase n3. By increasing n3,
one increases the number of attempts within 5 seconds to
get an errorless reception of the long Mode-S. As the
squitter rate averages 2 Hz, there will be at least 9
tries within 5 seconds. If x represents the number of
attempts to receive an errorless squitter message, then
the probability that at least one squitter message per
aircraft will be received without error is

$$1 - (1 - p)^x \qquad\qquad (2)$$

where the p is as defined in equation (1). The graphs in
Figures 1 and 2 display three cases. It is assumed that
x will increase in direct proportion to n3. Note that
doubling n3 (case II) gives a gain, but increasing n3 by
a factor of 16 (case III) reduces the capacity below that
which was achieved by simply doubling n3. What is
happening, of course, is that more and more interference
is being created as n3 increases.

BRIEF SUMMARY OF THE INVENTION

The present invention increases the capacity of
a Mode-S system by sectorizing with the use of
directional Mode-S antennas, particularly by the use of
an inexpensive Mode-S, quarter wavelength, single
element, stub antenna.

The present invention uses an array of basic Mode-S antenna elements, and processes the ensemble of signals electronically. To operate in denser environments, more antenna elements could be added as

5   needed. Generally, given N antenna elements, it is possible to steer N-1 nulls.

The digital receiving system for dense environment of aircraft of the present invention is a signal processing/receiver architecture which increases

10   the capacity of the Mode-S ADS-B system so that it is capable of effectively functioning within a highly congested airspace.

This invention has very significant primary and secondary benefits, and can provide a clear and cost

15   effective path to realizing the ADS-B function in a manner which is scalable and uses extant equipment to the maximum extent possible.

The primary benefits are that the invention is scalable, and is continuously upgradable for increased

20   capacity, is backwards compatible, should be relatively low cost to manufacture, presents worldwide frequency spectrum allocation and approval, transponder maturity - the Mode-S system is well known and accepted, and also can be used to counter and null out multipath by

25   attenuating gain direction.

The secondary benefits are that the invention is frequency friendly, with the short wavelength enabling a significant realizable aperture, there are no moving parts to the antenna aperture, there is no active control

30   of antenna elements, e.g. no component phase shifters, provides security, e.g. it can easily null out a jammer or a rogue transmitter, can be used to backup a failed

GNSS (Global Navigation Satellite System), can also check the consistency of other users' GNSS, and can be used to support direct sequence spread spectrum communications to counter a "near/far" problem.

BRIEF DESCRIPTION OF THE DRAWINGS

Figures 1 and 2 present graphs of respectively the probability of a specific squitter being received correctly, and the probability of at least one squitter being received correctly for three cases:
case 1, $x=9$, $n3=6$; case 2, $x=18$, $n3=12$; and case 3, $x=144$, $n3=96$.

Figure 3 is a schematic block diagram of one embodiment of a digital receiving system for dense environment of aircraft pursuant to the invention.

DETAILED DESCRIPTION OF THE INVENTION

The present invention increases the capacity of the Mode-S system by sectorizing the antenna response with a multi-element antenna in a manner that is generally well known in the prior art. The TCAS (Traffic Alert and Collision Avoidance System) equips an aircraft with a directional antenna. In aircraft equipped with TCAS and Mode-S, the TCAS and Mode-S communicate internally via the 429 bus. The Mode-S uses a 2" high, quarter wavelength, single element, stub antenna. The TCAS uses an antenna array. One of these arrays appears somewhat like a "FRISBEE®" with a 9" diameter and a protrusion of about 1" above the aircraft skin. The antenna is steered and provides an estimate of the bearing of the received signal. The cost of a Mode-S antenna is on the order of $150 or less. The cost of a

TCAS antenna is on the order of $10K. Also, the TCAS
antenna must be matched to the specific TCAS processing
unit.

The present invention uses a basic Mode-S
5 antenna but adds more of them and processes the ensemble
of signals electronically. The cost of electronics
continues to decline and the ability to perform
increasingly complex and rapid signal processing
continues to grow. To operate in ever denser
10 environments, more antenna elements could be added as
needed. As a general rule of thumb, given N antenna
elements, it is possible to steer N-1 nulls.

The digital receiving system for dense
environment of aircraft of the present invention uses a
15 signal processing/receiver architecture which increases
the capacity of the Mode-S ADS-B system to be capable of
effectively functioning within a highly congested
airspace such as is specified by the Los Angeles Basin
traffic model. It operates as follows:

20 (1) Referring to Figure 3, a spatial array of
antenna elements 10 is established on the aircraft.

(2) The output of each antenna element 10 is
amplified by a preamplifier 12.

(3) The output of each preamplifier 12 is
25 down-converted by a down converter 14 using a local
oscillator (not shown).

(4) The output of each down converter 14 is
filtered by a filter 16 to remove out-of-band signal
energy.

30 (5) The outputs of the filters are sequentially
and periodically connected to a high-rate
analog-to-digital converter (A/D) 20 by a multiplexer 18.

The A/D converter samples the output of the filter to
which it is connected and which produces pairs of
time-offset samples for each filter output. In an
alternative embodiment, a separate A/D converter 36 can
5   be provided for each signal from each antenna element,
and the outputs connected to a digital multiplexer.

(6) One of the time-offset samples is Hilbert
transformed by a Hilbert Transform filter (approximation)
22 to produce a quadrature I and Q sample pair.

10   (7) The sample pairs are stored in two cascaded
Memory/Buffer units 24 and 26.

(8) A surface acoustic wave (SAW) filter 28, or
an equivalent filter, constantly looks for the presence
of a squitter preamble, i.e., it constantly convolves the
15   coherent output of a single, and therefore nearly
omnidirectional, antenna element with the squitter
preamble signature. The output of the SAW filter 28 is
input to a controller unit 30.

(9) A digital signal processing unit 32
20   interfaces with controller unit 30, and produces an
output to a Mode-S receiver (RCVR) 34.

(10) The controller unit 30 has a complex set of
responsibilities. On notification by the SAW filter 28
that a squitter preamble is present, the controller 30:
25   a.   Isolates the Mode-S message in the right
most memory/buffer 26 where it causes the Mode-S message
to be retained until processing is complete;
.b.   The controller 30 directs the digital
signal processing unit 32 to adjust the complex weights
30   of all antenna element samples in order to maximize the
signal-to-noise ratio of the isolated Mode-S message.
There are a number of algorithms by which this can be

accomplished. For example, as the preamble is known, it can be used to guide an adaptive beamforming algorithm or decision directed search;

c. Once the signal-to-noise ratio has been maximized, the controller 30 orders the digital signal processing unit 32 to output the cleaned Mode-S message to the Mode-S receiver 34 and allows the memory/buffer units 24 and 26 to resume operation in cascade.

The function of the digital signal processing unit 32 is generally well known in the art, and after a Mode-S signal is detected, the digital signal processing unit 32 processes and adjusts complex weights of the digital signals for the separate antenna elements' signals to maximize the signal-to-noise ratio of the received Mode-S signal, in a manner as is generally well known in the art.

The controller unit 30 basically controls the functions being performed by the memory buffers 24, 26 and the digital signal processor 32. The controller unit 30 controls the memory/buffers 24, 26 and the digital signal processing unit 32. The controller unit 30, upon receiving a signal from the squitter filter 28 that a squitter preamble has been detected, controls the memory/buffers 24, 26 to isolate the Mode-S signal in the second memory/buffer 26 wherein the Mode-S signal is retained until processing is completed. The controller unit 30 also directs the digital signal processing unit 32 to commence processing to adjust complex weights of all antenna element digital signals to maximize the signal-to-noise ratio of the isolated Mode-S signal. After the digital processing unit has completed processing to maximize the signal-to-noise ratio, the

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controller unit 32 directs the digital signal processing
unit 30 to output the Mode-S signal to the Mode-S
receiver 34, and directs the memory/buffers 24, 26 to
resume a normal sequenced operation.

5   Many possible algorithms can be implemented by
the DSP 32. For example, if the direction-of-arrival
estimation were done on the preamble of a Mode-S message,
then other messages could be rejected. The rejection
could be temporary, i.e., the latter message(s) could be
10   delayed for subsequent processing or handed off to a
parallel chain for processing. The rejection can use a
power minimization technique with a response constraint
in the direction of the message transmitter.

This invention has very significant primary and
15   secondary benefits, and can provide a clear and cost
effective path to realizing the ADS-B function in a
manner which is scalable and uses extant equipage to the
maximum extent possible. In summary, the benefits are:

The primary benefits are that the invention is
20   scalable, and is continuously upgradable for increased
capacity, is backwards compatible, should be relatively
low cost to manufacture, presents worldwide frequency
spectrum allocation and approval, transponder maturity –
the Mode-S system is well known and accepted, and also
25   can be used to counter and null out multipath by
attenuating gain direction.

The secondary benefits are that the invention
is frequency friendly, with the short wavelength enabling
a significant realizable aperture, there is no active
30   control of antenna elements, e.g. no component phase
shifters, provides security, e.g. it can easily null out
a jammer or a rogue transmitter, can be used to backup a

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failed GNSS (Global Navigation Satellite System), can also check the consistency of other users' GNSS, and can be used to support direct sequence spread spectrum communications to counter a "near/far" problem.

5   While several embodiments and variations of the present invention for a digital receiving system for dense environment of aircraft are described in detail herein, it should be apparent that the disclosure and teachings of the present. invention will suggest many

10   alternative designs to those skilled in the art.

WHAT IS CLAIMED IS:

1. A Mode-S digital receiving system for
receiving and processing Mode-S signals in an aircraft
operating in a dense environment of aircraft comprising:

a. a spatial array of Mode-S antenna
elements mounted on the aircraft;

b. a signal processing receiver for
producing and processing a separate signal for each
separate antenna element;

c. at least one analog to digital (A/D)
converter for converting the signals for the separate
antenna elements to corresponding digital signals;

d. a multiplexer for sequentially and
periodically sampling the signals or digital signals for
the separate antenna elements;

e. a squitter filter for determining the
presence of a squitter preamble in a Mode-S signal
received by the receiving system;

f. a digital signal processing unit,
responsive to the determined presence of a Mode-S signal,
for processing and adjusting complex weights of the
digital signals for the separate antenna element signals
to maximize the signal-to-noise ratio of the received
Mode-S signal;

g. A Mode-S receiver, coupled to the
output of the digital signal processing unit, for
processing and identifying the technical data conveyed by
the Mode-S signal.

2. The Mode-S digital receiving system of
claim 1, wherein:

3   a. a memory/buffer stores the digital
4   signals in sequence therein;
5   b. a controller unit is coupled to the
6   output of the squitter filter and controls the
7   memory/buffer and the digital signal processing unit,
8   wherein the controller unit, upon being notified by the
9   squitter filter that a squitter preamble is present,
10   isolates the Mode-S signal in the
11 memory/buffer wherein the Mode-S signal is retained until
12 processing is completed,
13   directs the digital signal processing unit
14 to adjust complex weights of all antenna element digital
15 signals to maximize the signal-to-noise ratio of the
16 isolated Mode-S signal, and
17   after the signal-to-noise ratio has been
18 maximized, the controller unit directs the digital signal
19 processing unit to output the Mode-S signal to the Mode-S
20 receiver, and directs the memory/buffer to resume
21 sequenced operation.

1   3.   The Mode-S digital receiving system of
2   claim 2, wherein:
3   a. the analog to digital (A/D) converter
4   produces a pair of time offset digital signals for each
5   signal;
6   b. a Hilbert Transform filter Hilbert
7   transforms one of the pair of time offset digital signals
8   to produce a quadrature I and Q sample pair which is
9   directed as an input to the memory/ buffer.

1   4.   The Mode-S digital receiving system of
2 claim 1, wherein each Mode-S antenna element comprises a
3 quarter wavelength, single element, stub antenna.

1   5.   The Mode-S digital receiving system of
2 claim 1, wherein in the signal processing receiver, each
3 antenna element has associated therewith:
4   a. a preamplifier for amplifying the
5 output of the antenna element;
6   b. a frequency down converter for
7 frequency down converting the output of the preamplifier;
8 and
9   c. a filter for filtering the output of
10 the down converter to remove out of band signal energy,
11 to produce the signal output.

1   6.   The Mode-S digital receiving system of
2 claim 2, wherein the memory/buffer comprises first and
3 second cascaded memory/buffer units.

1   7.   The Mode-S digital receiving system of
2 claim 6, wherein the controller unit, upon being notified
3 that a squitter preamble is present, isolates the Mode-S
4 signal in the second memory/buffer unit.

1   8.   The Mode-S digital receiving system of
2 claim 1, wherein the squitter filter comprises a surface
3 acoustic wave filter which constantly convolves a
4 filtered output of an antenna element with a squitter
5 preamble signature to determine the presence of a
6 squitter preamble.

1   9.   A method for receiving and processing
2   Mode-S signals in an aircraft operating in a dense
3   environment of aircraft comprising:
4   a. mounting a spatial array of Mode-S
5   antenna elements on the aircraft;
6   b. producing and processing a separate
7   signal for each separate antenna element;
8   c. converting the signals for the separate
9   antenna elements to corresponding digital signals;
10   d. sequentially and periodically sampling
11 the signals or digital signals for the separate antenna
12 elements;
13   e. determining the presence of a squitter
14 preamble in a Mode-S signal received by the receiving
15 system;
16   f. in response to the determined presence
17 of a Mode-S signal, processing and adjusting complex
18 weights of the digital signals for the separate antenna
19 element signals to maximize the signal-to-noise ratio of
20 the received Mode-S signal;
21   g. processing and identifying the
22 technical data conveyed by the maximized signal-to-noise
23 ratio Mode-S signal.

1   10.   The method of claim 9, comprising:
2   a. storing the digital signals in sequence
3   in a memory/buffer;
4   b. a upon determining that presence of a
5   squitter preamble,
6   isolating the Mode-S signal in the
7   memory/buffer wherein the Mode-S signal is retained until
8   processing is completed,

9   adjusting complex weights of all antenna
10   element digital signals to maximize the signal-to-noise
11   ratio of the isolated Mode-S signal, and
12   after the signal-to-noise ratio has been
13   maximized, outputting the Mode-S signal, and resuming
14   sequenced operation of the memory/buffer.

1   11.   The method of claim 10, comprising:
2   a. producing a pair of time offset digital
3   signals for each signal;
4   b. transforming one of the pair of time
5   offset digital signals to produce a quadrature I and Q
6   sample pair which is directed as an input to the memory/
7   buffer.

1   12.   The method of claim 9, comprising mounting
2   a spatial array of quarter wavelength, single element,
3   stub antennas.

1   13.   The method of claim 9, comprising:
2   a. preamplifying the output of each
3   antenna element;
4   b. frequency down converting the output of
5   each preamplifier; and
6   c. filtering the output of each down
7   converted output to remove out of band signal energy.

1   14.   The method of claim 10, comprising
2   providing first and second cascaded memory/buffer units,
3   and upon being notified of the presence of a squitter
4   preamble, isolating the Mode-S signal in the second
5   memory/buffer unit.

1   15.   The method of claim 9, comprising

2   employing a surface acoustic wave filter which constantly

3   convolves a filtered output of an antenna element with a

4   squitter preamble signature to determine the presence of

5   a squitter preamble.

Fig. 1

Fig. 2
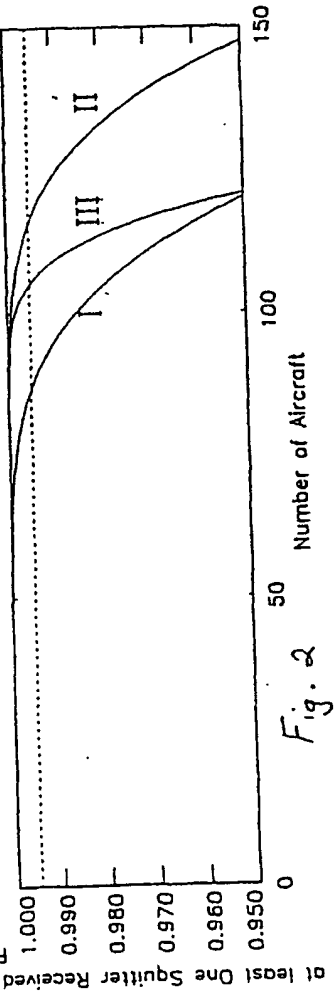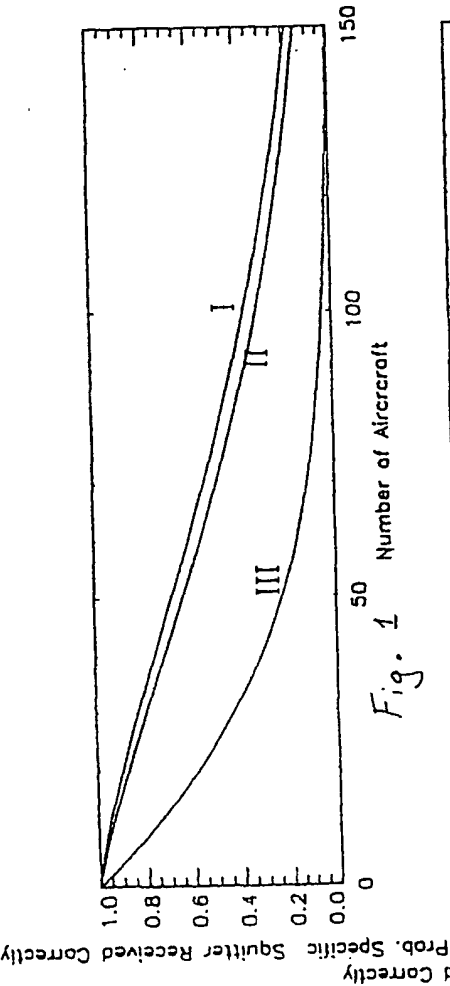
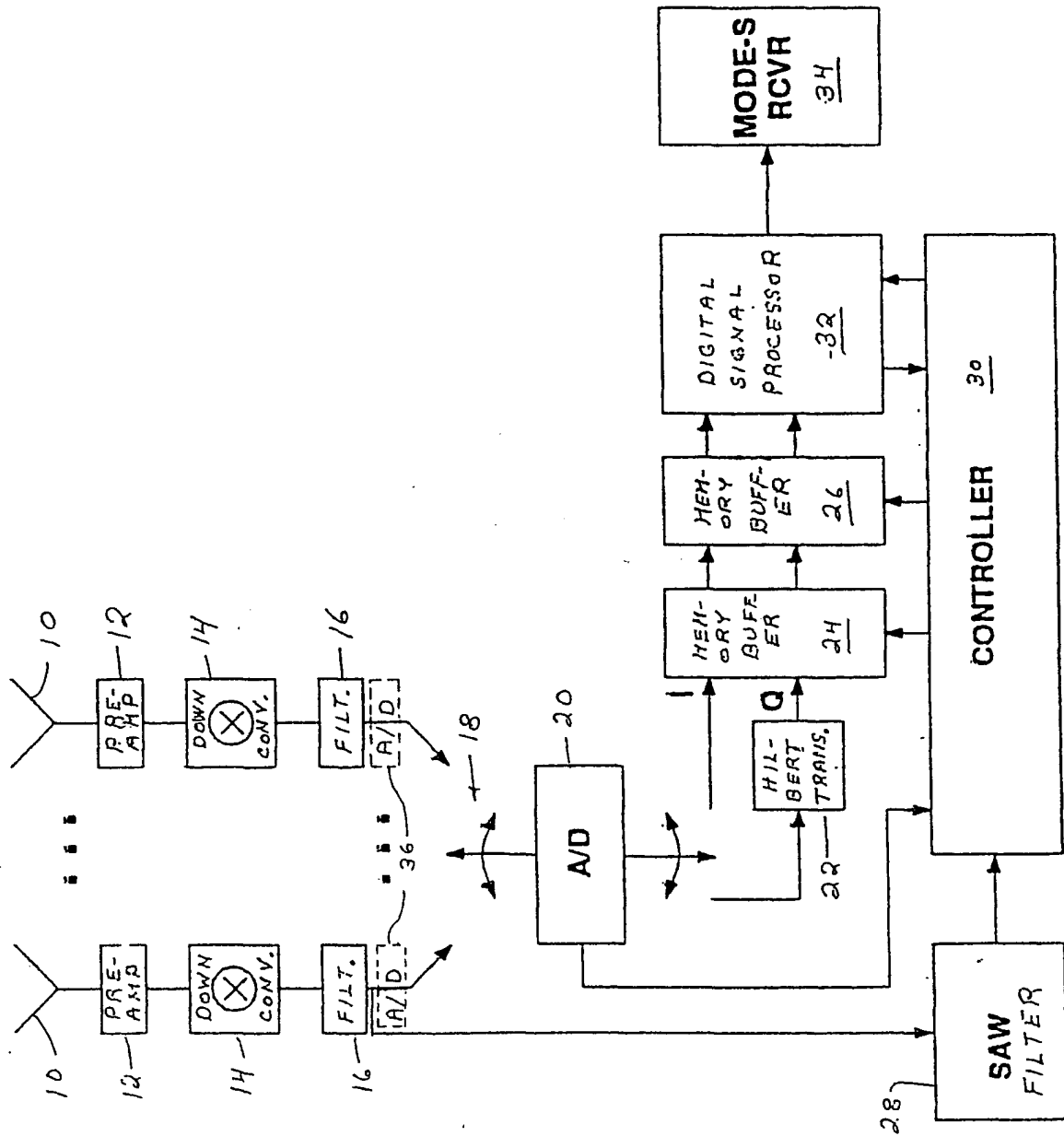Case I: $x = 9$, $n_3 = 6$
Case II: $x = 18$, $n_3 = 12$
Case III: $q = 144$, $n_3 = 96$

Figure 3

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